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On hydrogen and hydrogen energy strategies II: future projections affecting global stability and unrest

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Abstract

This article focuses on hydrogen energy strategies and discusses the key role of hydrogen as an energy carrier in this century and beyond. Two important empirical relations that describe the effects of fossil fuels on world peace and global unrest are developed. These relations incorporate predicted utilization ratios for hydrogen energy from non-fossil fuels, and are used to investigate whether hydrogen utilization can reduce the negative global effects related to fossil fuel use, eliminate or reduce the possibilities of global energy conflicts, and contribute to achieving world peace and stability. Consequently, the highest levels of global peace and global unrest can be estimated. If hydrogen use from non-fossil fuels increases, for a fixed usage of petroleum, coal and natural gas, the level of global unrest decreases. However, if the utilization ratio of hydrogen energy from non-fossil fuels is lower than 100%, the level of global peace decreases as the symptoms of global unrest increase. Thus, to reduce the causes of global unrest and increase the likelihood of global peace in the future, it is suggested that hydrogen energy be widely and efficiently used as part of sustainable technologies and systems. It is expected that the results of this study will be of use to decision makers and scholars who want to develop and promote the use of hydrogen-based technologies and solve future energy and environment related problems globally.

Keywords: Energy; Hydrogen; Fossil fuel; Global peace; Global unrest; Renewable energy

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Contents

Nomenclature

Q_{wpe}	quantity of world primary energy, Mtoe
U_c	utilization of coal, Mtoe
U_{H_2}	utilization of hydrogen from non-fossil fuels, Mtoe
U_{ng}	utilization of natural gas, Mtoe
U_P	utilization of petroleum, Mtoe

Greek letters

β_u	utilization efficiency factor
ϕ_{cu}	utilization ratio of coal after hydrogen usage from non-fossil fuels
ϕ_{ffu}	total utilization ratio of fossil fuels after hydrogen usage from non-fossil fuels
ϕ_{ngu}	utilization ratio of natural gas after hydrogen usage from non-fossil fuels
ϕ_{pu}	utilization ratio of petroleum after hydrogen usage from non-fossil fuels
Θ_{global}	level of global unrest
ξ_{global}	level of global peace
ψ_{cu}	utilization ratio of coal
ψ_{ffu}	total utilization ratio of fossil fuels
ψ_{H_2-C}	utilization of hydrogen from non-fossil fuels at a certain utilization ratio of coal
ψ_{H_2-ff}	total utilization ratio of hydrogen from non-fossil fuels at certain utilization ratios of fossil fuels
ψ_{H_2-ng}	utilization of hydrogen from non-fossil fuels at a certain utilization ratio of natural gas
ψ_{H_2-P}	utilization of hydrogen from non-fossil fuels at a certain utilization ratio of petroleum
ψ_{ngu}	utilization ratio of natural gas
ψ_{pu}	utilization ratio of petroleum

1. Introduction

The idea of using hydrogen as a fuel is not new, but interest in it has grown in recent years. As early as 1874, a character in Jules Verne's novel, *The Mysterious Island*, suggested that when fossil fuel supplies run out, hydrogen "will furnish an inexhaustible source of heat and light". So far, however, this idea has generated much research but little commercial application.

Energy is a key element in the interactions between nature and society and is considered a key requirement for economic development. Many environmental issues, for example, acid precipitation, stratospheric ozone depletion and global climate change, are caused by or relate to the production, conversion and use of energy. Environmental issues span a continuously growing range of pollutants, hazards and eco-system degradation factors that affect areas ranging from local through regional to global. Some of these concerns arise from observable, chronic effects on, for instance, human health, while others stem from actual or perceived environmental risks such as possible accidental releases of hazardous materials.

Reasons why hydrogen is one of the most promising future energy carriers include that it can be used efficiently and be low polluting. When hydrogen is used in a fuel cell to generate electricity or is combusted with air, the only products are water and a small amount of NO_x. Hydrogen can be generated renewably and is found in many compounds such as water, fossil fuels, and biomass.

Hydrogen typically makes up about 6% by weight of dry biomass. Using biomass energy results in lower emissions than using fossil fuels. CO_2 is continuously recycled as biomass in the form of trees and other plants that use it to regenerate, and lower emissions of sulfur and NO_x are normally generated when using woody biomass in comparison to coal. To obtain hydrogen from biomass, pyrolysis or gasification is used, which typically yields a gas containing 20% hydrogen by volume, and which can be further steam-reformed to make higher-purity streams for fuel cells. The challenge for biomass utilization is to overcome the economic barriers that current technology presents for converting biomass to hydrogen for use in clean, efficient energy-conversion devices [1].

Hydrogen produced from non-fossil fuels (e.g., renewable resources) and used in fuel cells can provide sustainable energy to drive electric vehicles and other devices. The total hydrogen system, including distribution, refueling and on-board storage of hydrogen, may prove superior to batteries recharged with grid power. A hydrogen-powered electric vehicle may offer a market entry for hydrogen and renewable resources in transportation. Attractive transitional applications of hydrogen include its use in combustion engine vehicles. The environmental and energy policy consequences are significantly less with hydrogen than with continued use of fossil fuel-derived fuels in conventional combustion engine vehicles. Fuel cells, which employ hydrogen to produce electricity, can be used to power a wide variety of applications ranging from laptops to power plants [2].

The primary objective of this study is to investigate the key role of hydrogen as an energy carrier in this century and beyond. For this purpose two important empirical relations are developed, using utilization ratios of hydrogen from non-

fossil fuels, that describe the effect of fossil fuels on world peace and global unrest. These relations suggest that hydrogen is an important and valuable future energy carrier because it is advantageous and safe for transportation and benign regarding the environment, and it has the highest utilization efficiency and the lowest effective cost. Consequently, a transition to hydrogen energy should be encouraged to reduce and/or stop the negative effects related to fossil energy sources. Moreover, all developed countries should increase investments in hydrogen energy from non-fossil fuels and related technologies. Such measures may prevent the world energy conflicts and contribute to achieving global peace.

2. A new quantification of global stability and unrest

Energy is a key factor in discussions of economic, social and environmental dimensions of sustainable development [3]. Fossil fuels such as petroleum, coal and natural gas, which have been extensively utilized in industrial and domestic applications for a long time, have often been the cause of global destabilization and unrest. This problem is likely to increase in significance in the future and suggests the need for investigations of, among other factors, the role of hydrogen energy relative to future global peace and peace. Note that hydrogen is an energy carrier, not an energy source; hydrogen can be produced from non-fossil fuel sources (e.g., water, biomass) by using renewable energy sources.

2.1. Global unrest

Here, we introduce a new quantitative measure of the level of global unrest based on the utilization ratios of petroleum, coal and natural gas as a function of the following significant parameters

- quantity of world energy sources, Q_{wpe}
- utilization of petroleum, coal and natural gas, respectively, U_{p}, U_{c} and U_{ng}
- utilization of hydrogen from non-fossil fuels, $U_{\mathrm{H_2}}$
- utilization of hydrogen from non-fossil fuels at a certain utilization ratio of petroleum, $\psi_{\mathrm{H_2-P}}$
- utilization of hydrogen from non-fossil fuels at a certain utilization ratio of coal, $\psi_{\mathrm{H_2-C}}$
- utilization of hydrogen from non-fossil fuels at a certain utilization ratio of natural gas, $\psi_{\mathrm{H_2-ng}}$
- total utilization ratio of hydrogen from non-fossil fuels at certain utilization ratios of fossil fuels, $\psi_{\mathrm{H_2-ff}}$

In general, the global unrest arising from the use of fossil fuels is considered as a function of the usage ratios of these fossil fuels. Thus, the following definitions and

relations are considered:

$$\psi_{\mathrm{pu}} = \frac{U_{\mathrm{P}}}{Q_{\mathrm{wpe}}} = \frac{\text{Utilization of petroleum}}{\text{quantity of world primary energy}} < 1 \quad \text{and } (U_{\mathrm{P}} < Q_{\mathrm{wpe}}) \tag{1}$$

$$\psi_{\mathrm{cu}} = \frac{U_{\mathrm{C}}}{Q_{\mathrm{wpe}}} = \frac{\text{Utilization of coal}}{\text{quantity of world primary energy}} < 1 \quad \text{and } (U_{\mathrm{C}} < Q_{\mathrm{wpe}}) \tag{2}$$

$$\psi_{\mathrm{ngu}} = \frac{U_{\mathrm{ng}}}{Q_{\mathrm{wpe}}} = \frac{\text{Utilization of natural gas}}{\text{quantity of world primary energy}} < 1 \quad \text{and } (U_{\mathrm{ng}} < Q_{\mathrm{wpe}}) \tag{3}$$

The use of world primary energy generally changes each year, and in general has grown with increasing population and technology advances.

The total utilization ratio of fossil fuels is related to ψ_{pu}, ψ_{cu} and ψ_{ngu} and can be estimated as

$$\psi_{\mathrm{ffu}} = \psi_{\mathrm{pu}} + \psi_{\mathrm{cu}} + \psi_{\mathrm{ngu}} \tag{4}$$

Moreover, the utilization ratios of petroleum, coal and natural gas after hydrogen usage from non-fossil fuels can be written as

$$\phi_{\mathrm{pu}} = \psi_{\mathrm{pu}} - \psi_{\mathrm{H_2-P}} \tag{5}$$

$$\phi_{\mathrm{cu}} = \psi_{\mathrm{cu}} - \psi_{\mathrm{H_2-C}} \tag{6}$$

$$\phi_{\mathrm{ngu}} = \psi_{\mathrm{ngu}} - \psi_{\mathrm{H_2-ng}} \tag{7}$$

where $\psi_{\mathrm{H_2-P}}$ denotes the utilization ratio of hydrogen from non-fossil fuels at a certain utilization ratio of petroleum, $\psi_{\mathrm{H_2-C}}$ the utilization ratio of hydrogen from non-fossil fuels at a certain utilization ratio of coal, and $\psi_{\mathrm{H_2-ng}}$ the utilization ratio of hydrogen from non-fossil fuels at a certain utilization ratio of natural gas.

Using Eqs. (5)–(7), the total utilization ratio of fossil fuels, assuming the utilization of hydrogen from non-fossil fuels at a certain utilization ratio of fossil fuels, can be written as

$$\phi_{\mathrm{ffu}} = \phi_{\mathrm{pu}} + \phi_{\mathrm{cu}} + \phi_{\mathrm{ngu}} \tag{8a}$$

$$\phi_{\mathrm{ffu}} = \psi_{\mathrm{ffu}} - (\psi_{\mathrm{H_2-P}} + \psi_{\mathrm{H_2-C}} + \psi_{\mathrm{H_2-ng}}) \tag{8b}$$

where

$$\psi_{\mathrm{H_2-ff}} = \psi_{\mathrm{H_2-P}} + \psi_{\mathrm{H_2-C}} + \psi_{\mathrm{H_2-ng}} \tag{9}$$

Substituting Eq. (9) into Eq. (8b), we obtain

$$\phi_{\mathrm{ffu}} = \psi_{\mathrm{ffu}} - \psi_{\mathrm{H_2-ff}} \tag{10}$$

With the total utilization ratios of fossil fuels (ψ_{ffu}), we will be able to define the negative effects of using these fuels in the world. This will bring up the definition of the quantitatively global unrest (Θ_{global}), and we define it as the negative effects of all the problems caused by fossil fuel utilization, world fossil energy demand, increase of fossil energy consumption per capita, technological developments based

on the fossil energy sources, etc. Actually, no theoretical and/or experimental and/or computational information or data on the level of the global unrest as well as global peace have been found in literature so far. Therefore, this study aims to present this approach to identify and estimate the levels of global unrest and global peace in a quantitative form for comparison purposes. As indicated, some statistical data from literature (e.g., [4]) are employed to highlight the importance of the topic.

In order to identify and estimate the level of global unrest accordingly, it is important to select a proper reference value. For this purpose, it is assumed that the lowest value of global unrest and the highest value of global peace are equal to 1 that is a reference point to evaluate the interactions between global unrest and global peace, which is defined in the sub title "global peace". The level of global unrest needs to be expressed mathematically as a function of the utilization ratios of fossil fuels after hydrogen usage from non-fossil fuels (ϕ_{ffu}). In this case, the mathematical form of the global unrest is written as follows:

$$\Theta_{\text{global}} = \frac{1}{(1-\phi_{\text{ffu}})} \tag{11}$$

It is useful to express the level of global unrest, as dependent on the utilization ratios of hydrogen from non-fossil fuels at a certain ratio of petroleum, hydrogen from non-fossil fuels at a certain ratio of coal, and hydrogen from non-fossil fuels at a certain ratio of natural gas as follows:

$$\Theta_{\text{global}} = \frac{1}{1-(\psi_{\text{ffu}}-(\psi_{\text{H}_2-\text{P}}+\psi_{\text{H}_2-\text{C}}+\psi_{\text{H}_2-\text{ng}}))} \tag{12}$$

Consequently, based on Eqs. (1)–(12) and taking into consideration the above assumption, the general algebraic case form of global unrest expression proposed is as follows:

$$\Theta_{\text{global}} = \left\{1-\left[\left(\frac{U_{\text{p}}}{Q_{\text{wep}}}+\frac{U_{\text{c}}}{Q_{\text{wep}}}+\frac{U_{\text{ng}}}{Q_{\text{wep}}}\right)-(\psi_{\text{H}_2-\text{P}}+\psi_{\text{H}_2-\text{C}}+\psi_{\text{H}_2-\text{ng}})\right]\right\}^{-1} \tag{13}$$

As seen in Eq. (13), the level of global unrest is a function of utilization ratios of coal, petroleum and natural gas, and utilization ratios of hydrogen from non-fossil fuels at certain utilization ratios of these fossil fuels. In order to determine the intervals of the general case form of global unrest expression, Eq. (13) should be theoretically analyzed and justified in the scope of the above assumption. If the total utilization ratio of hydrogen from non-fossil fuels at certain utilization ratios of fossil fuels is equal to total utilization ratio of fossil fuels

$$\psi_{\text{H}_2-\text{ff}} = \psi_{\text{ffu}} = \frac{U_{\text{p}}}{Q_{\text{wep}}}+\frac{U_{\text{c}}}{Q_{\text{wep}}}+\frac{U_{\text{ng}}}{Q_{\text{wep}}} = \psi_{\text{H}_2-\text{P}}+\psi_{\text{H}_2-\text{C}}+\psi_{\text{H}_2-\text{ng}},$$

the value of the total utilization ratio of fossil fuels after hydrogen usage from non-

fossil fuels will be zero

$$\phi_{\mathrm{ffu}} = \left[\left(\frac{U_{\mathrm{p}}}{Q_{\mathrm{wep}}} + \frac{U_{\mathrm{c}}}{Q_{\mathrm{wep}}} + \frac{U_{\mathrm{ng}}}{Q_{\mathrm{wep}}}\right) - (\psi_{\mathrm{H_2-P}} + \psi_{\mathrm{H_2-C}} + \psi_{\mathrm{H_2-ng}})\right] = 0.$$

In this case, the level of global unrest is unity, as shown in Eq. (13) ($\Theta_{\mathrm{global}} = 1$). This is a condition for the lowest level of global unrest, and means that the negative effects from the utilization and requirement of fossil fuels are reduced to a minimum level. However, the total utilization ratio of hydrogen from non-fossil fuels at certain utilization ratios of fossil fuels will be equal to zero ($\psi_{\mathrm{H_2-ff}} = \psi_{\mathrm{H_2-P}} + \psi_{\mathrm{H_2-C}} + \psi_{\mathrm{H_2-ng}} = 0$) if world energy demands are completely provided from fossil fuel sources. Then, the level of global unrest becomes infinite ($\Theta_{\mathrm{global}} = \infty$). For normal conditions, the level of global unrest varies between 1 and ∞, depending on the parameters ψ_{ffu} and $\psi_{\mathrm{H_2-ff}}$. The level of global unrest should be closer to 1 to increase the level of global peace. Generally, it is seen from Eq. (13) that global unrest increases as the consumption of fossil fuels increases. In order to decrease global unrest stemming from fossil fuels usage, the authors suggest that, instead of fossil fuels, the utilization ratio of hydrogen obtained from non-fossil fuels by using renewable energy resources, should be increased in industrial and domestic applications. This measure will reduce the utilization of fossil fuels.

2.2. *Global peace*

Here, we introduce another significant parameter as a quantitative measure of the level of global peace, based on the utilization ratios of petroleum, coal and natural gas as a function of the above parameters. Considering these parameters, the interactions of global peace with hydrogen energy from non-fossil fuels and fossil fuels such as petroleum, coal and natural gas are demonstrated in Fig. 1. This figure illustrates the interactions of global peace with hydrogen energy and fossil fuel utilization. In this figure, the utilization ratios for petroleum, coal and natural gas before and after 2004 are parametrically shown as ψ_{pu}, ψ_{cu}, ψ_{ngu}, ϕ_{pu}, ϕ_{cu} and ϕ_{ngu}, respectively. Moreover, the levels of global peace resulting from decreases or increases of these ratios before and after 2004 are given as ξ_{global}. Generally, it is expected that the level of global peace will decrease due to an increase in fossil fuel utilization. This figure shows that, after 2004, if hydrogen produced from non-fossil fuel sources is utilized instead of petroleum, coal and natural gas, the level of global peace will increase.

To improve understanding, the utilization ratio of hydrogen from non-fossil fuels is defined and its relationship with the level of global peace. The utilization ratio of hydrogen from non-fossil fuels is the ratio of hydrogen utilization from non-fossil fuels to the quantity of world primary energy:

$$\psi_{\mathrm{H_2}} = \frac{U_{\mathrm{H_2}}}{Q_{\mathrm{wpe}}} = \frac{\text{utilization of hydrogen from non-fossil fuels}}{\text{quantity of world primary energy}} < 1, \quad (U_{\mathrm{H_2}} < Q_{\mathrm{wpe}}) \tag{14}$$

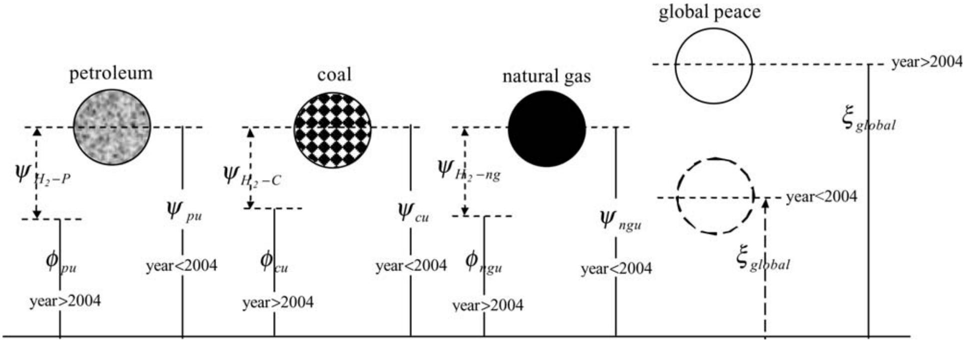


Fig. 1. The interaction of global peace with hydrogen from non-fossil fuels, petroleum, coal and natural gas.

An increase in hydrogen utilization from non-fossil fuels increases the value of the parameter ψ_{H_2}.

The relationship between global unrest and hydrogen utilization from non-fossil fuels can be explained considering the parameter ψ_{H_2}. It is known that global unrest results in large part from the utilization of petroleum, coal and natural gas. Also, the more fossil fuels are used, the more their reserves are decreased. This causes the following global problems:

- technological developments that are based on fossil fuels decrease or cease, leading to widespread unrest,
- the fossil fuel use per capita decreases, affecting individuals and societies,
- other problems are detailed in Fig. 1 presented in the first article as part 1 of this work, and
- the problems described above increase the requirement of a new energy carrier, which may be hydrogen.

Therefore, in order to decrease global unrest and increase the level of global peace, hydrogen from non-fossil fuels should be used, and encouraged for use, in technological developments and in industrial and domestic applications. The main benefit is derived from the substitution of hydrogen from non-fossil fuels for petroleum, coal and natural gas. Hydrogen derived from non-fossil sources can be substituted entirely for fossil fuels to attain the largest decrease in global unrest.

An increase in the utilization ratio of hydrogen from non-fossil fuels and a decrease in the level of global unrest refer to the decrease of the negative effects caused by fossil fuels. Additionally, an increase in the hydrogen utilization from non-fossil fuels may also decrease the requirement of fossil fuels. Thus, the term of global peace may be defined as the ratio of hydrogen utilization from non-fossil fuels (ψ_{H_2}) to the level of global unrest (Θ_{global}).

In order to identify and estimate the level of global peace quantitatively, it is assumed that the highest value of global peace is equal to 1 that is a reference

point to evaluate the interactions between global unrest and global peace. Thus, the relationship between global unrest and global peace can be written as a function of the utilization ratio of hydrogen from non-fossil fuels. It is proposed here that the algebraic case form of global peace ξ_{global} may be expressed as

$$\xi_{global} = \frac{\psi_{H_2}}{\Theta_{global}} \tag{15}$$

Substituting Eq. (12) into Eq. (15),

$$\xi_{global} = \psi_{H_2}(1 - (\psi_{ffu} - (\psi_{H_2-P} - \psi_{H_2-C} + \psi_{H_2-ng}))) \tag{16}$$

Also, substituting Eq. (9) into Eq. (16), the level of global peace can be expressed based on the utilization ratios of fossil fuels and hydrogen energy from non-fossil fuels:

$$\xi_{global} = \psi_{H_2}(1 - (\psi_{ffu} - \psi_{H_2-ff})) \tag{17}$$

Based on the utilization ratio of fossil fuels after hydrogen from non-fossil fuels is used in place of petroleum, coal and natural gas, the level of global peace is formulated as

$$\xi_{global} = \psi_{H_2}(1 - \phi_{ffu}) \tag{18}$$

Accordingly, based on Eqs. (13)–(18) and taking into consideration the above assumption, the general algebraic case form of global peace expression proposed is as follows:

$$\xi_{global} = \frac{U_{H_2}}{Q_{wep}} \times \left\{1 - \left[\left(\frac{U_p}{Q_{wep}} + \frac{U_c}{Q_{wep}} + \frac{U_{ng}}{Q_{wep}}\right) - (\psi_{H_2-P} + \psi_{H_2-C} + \psi_{H_2-ng})\right]\right\} \tag{19}$$

Eq. (19) is a function of utilization ratios of coal, petroleum and natural gas, and utilization ratios of hydrogen from non-fossil fuels at certain utilization ratios of these fuels, and utilization ratio of hydrogen from non-fossil fuels. In order to determine the interval of the general case form of global peace expression, Eq. (19) should be analyzed and justified in the scope of the above assumption. In this equation, it is known that the level of the case form of global unrest (Θ_{global}) varies between 1 and ∞ while ψ_{H_2} varies between 0 and 1, proportionally. Therefore, the maximum level of global peace is equal to 1 while Θ_{global} = the minimum level = 1 and ψ_{H_2} = the maximum level = 1. However, the level of global peace changes between 0 and 1 when Θ_{global} is larger than ψ_{H_2}. If ψ_{H_2} = the maximum value = 1 and world energy demand is completely provided from hydrogen from non-fossil fuels by using renewable energy sources, it can be assumed that no negative effects resulting from the utilization and requirement of fossil fuels will occur.

3. Results and discussion

The expressions introduced for global unrest and global peace (Eqs. (13) and (19)) can help us better understand and develop hydrogen energy strategies for the future. These expressions are dependent upon the amounts of petroleum, coal and natural gas consumed, annual quantities of world primary energy consumption and the predicted utilization ratios of hydrogen in place of fossil fuels (ranging from 0% to 100%). Several effects are now examined using Eqs. (13) and (19) and data from the literature (e.g., [4]).

Fig. 2 illustrates the variation of fossil fuel utilization as a function of the utilization ratio of hydrogen from non-fossil fuels. When no hydrogen is substituted for fossil fuels ($\psi_{H_2-ff} = 0$), the utilization ratio of fossil fuels is a maximum and varies between 0.86 and 0.74 from 1971 to 2030, respectively. The decrease as time progresses is based on an observed and anticipated continuous decrease in fossil fuels reserves. If the utilization ratio of hydrogen from non-fossil fuels is increased at a certain ratio of fossil fuels ($\psi_{H_2-ff} > 0$), then the utilization ratio of fossil fuels decreases ($\phi_{ffu} < \psi_{ffu}$). Considering Eq. (10), if the utilization ratio of hydrogen from non-fossil fuels instead of fossil fuels is equal to ψ_{ffu}, then fossil fuel utilization ratio ϕ_{ffu} is zero. Thus, the utilization of only hydrogen from non-fossil fuels continuously increases the lifetimes of fossil fuel reserves.

Fig. 3 shows the variation of the level of global unrest as a function of the hydrogen utilization ratio from non-fossil fuels. To better appreciate this figure, some of the key energy-related reasons for global unrest need to be understood:

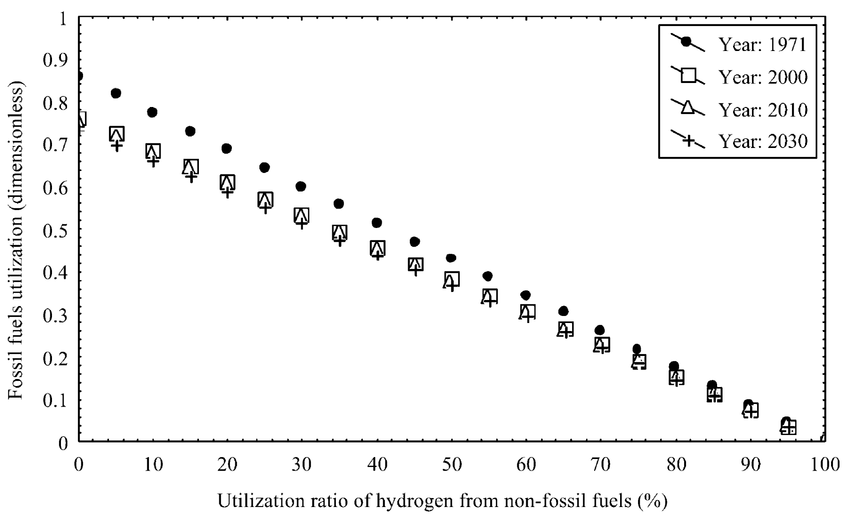


Fig. 2. Variation of fossil fuels utilization with utilization ratios of hydrogen from non-fossil fuels, for several years based, on data from Ref. [4].

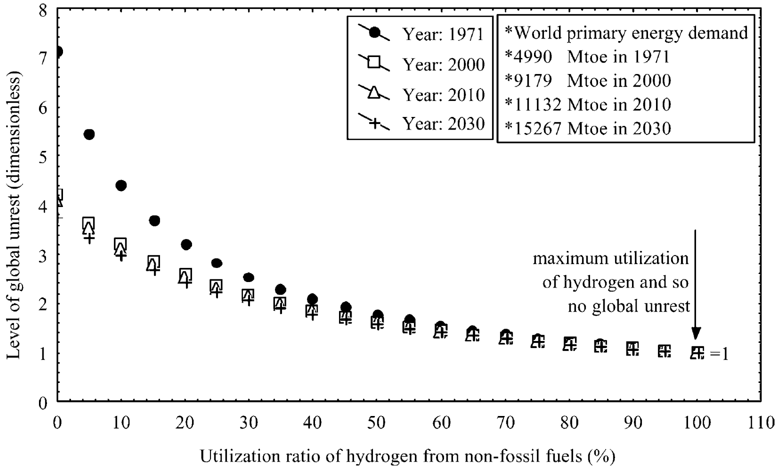


Fig. 3. Variation of the level of global unrest as a function of predicted hydrogen utilization ratio from non-fossil fuels, for several years, based on data from Ref. [4].

- increases in fossil fuel prices,
- environmental effects of energy use, including pollution due to emissions, stratospheric ozone layer depletion and global warming,
- decreases in the amount of fossil fuel available per capita and the associated decrease in living standards,
- increases in energy demand due to technological developments attributable to and based on fossil fuels,
- depletion of fossil fuel reserves,
- increases in conflicts for fossil fuel reserves throughout the world, and
- the lack of affordable and practical alternative energy sources to fossil fuels.

According to Fig. 3, the lowest level of global unrest ($\Theta_{\text{global}} = 1$) occurs when hydrogen from non-fossil fuels is substituted completely for fossil fuels. In general, the level of global unrest is higher than 1 and the problems causing global unrest can be reduced by using hydrogen energy from non-fossil sources instead of fossil fuels. Eq. (13) suggests that the utilization of hydrogen from non-fossil fuels at certain ratios of petroleum, coal and natural gas decreases the amount of fossil fuel consumption, and thus reduces the level of global unrest closer to 1. As shown in Fig. 3, the levels of global unrest are 7.14 in 1971, 4.24 in 2000, 4.07 in 2010 and 3.77 in 2030 when the utilization ratio of hydrogen is zero (i.e., when $\psi_{H_2-P} = 0$; $\psi_{H_2-C} = 0$; $\psi_{H_2-ng} = 0$).

Fig. 4 shows the variation in the level of global peace as a function of the hydrogen utilization ratio from non-fossil fuels. According to Fig. 4, if the utilization ratio of hydrogen from non-fossil fuels is lower than 100%, the level of global peace is less than 1 and the reasons for global unrest increase. Therefore, it is ben-

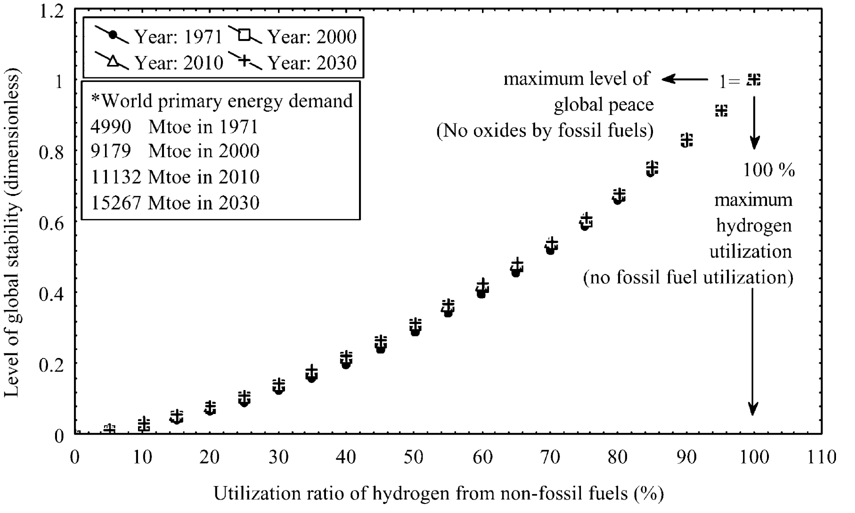


Fig. 4. Variation of the level of global peace as a function of predicted hydrogen utilization ratio from non-fossil fuels, for several years, based on data from Ref. [4].

eficial to encourage the utilization of hydrogen from non-fossil fuels in place of fossil fuels. The highest level of global peace is attained when 100% of hydrogen from non-fossil fuels is used in place of fossil fuels. Some advantages of having the highest level of global peace:

- Lifetimes of fossil fuel reserves are extended and real fossil fuel prices, consequently, can be held constant or reduced relative to present prices.
- Environmental effects from using fossil fuels are reduced or prevented because of the utilization of hydrogen from renewable energy sources and technologies.
- Technological developments based on hydrogen from non-fossil fuels increase and the requirement of technologies based on fossil fuels decrease.
- Living standards are probably higher than at present due in part to the increased consumption of the technologies related to hydrogen from renewable energy sources.
- Pressures to discover energy sources reduce because hydrogen can be abundantly produced, and conflicts for energy supplies subside.

Fig. 5 compares the levels of global unrest and global peace as a function of the predicted utilization ratio of hydrogen from non-fossil fuels. Eq. (19) indicates that there is an inversely proportional relationship between global peace and global unrest, depending on the utilization ratio of hydrogen from non-fossil fuels (ψ_{H_2}). As shown in Fig. 5, an increase in hydrogen utilization accordingly decreases the reasons for global unrest, allowing the benefits of global peace to be realized over time.

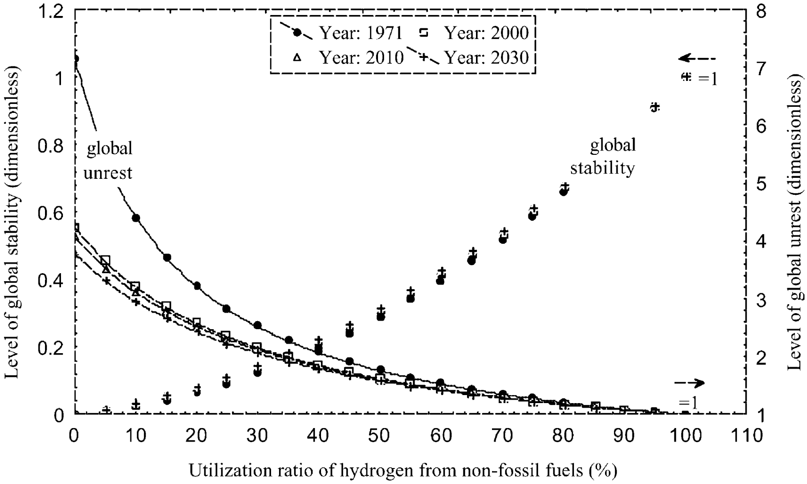


Fig. 5. Comparison of levels of global unrest and global peace as a function of hydrogen utilization ratios from non-fossil fuels.

To increase global peace, the relationship of hydrogen to renewable energy sources needs to be understood, as does the importance of producing hydrogen from renewable energy sources. Throughout this article, the required heat and electricity for hydrogen production from water or solid wastes containing carbon should come from renewable energy sources instead of fossil fuel energy sources, as highlighted by many sources. This idea is based on suggestions by others [5].

Fig. 6 describes routes using renewable energy sources for hydrogen production. As shown in Fig. 6, the utilization of hydrogen from non-fossil fuels reduces the negative energy-related environmental effects such as global climate change, and emissions of CO, CO_2, NO_x, SO_x, non-methane hydrocarbons, and particulate matter. To reduce these negative impacts, hydrogen should be produced from water or biomass by means of electrolysis or gasification technologies, and the required energy for this purpose should be supplied from the renewable energy sources.

By examining Figs. 2–5 and the expressions developed, the following important observations can be made:

- The level of global unrest cannot be lower than 1. When the level of global unrest is 1, the utilization of hydrogen from non-fossil fuels in place of fossil fuels is a maximum.
- If ψ_{pu}, ψ_{cu} and ψ_{ngu} increase, then ξ_{global} decreases and global unrest heightens,
- If ψ_{pu}, ψ_{cu} and ψ_{ngu} decrease, then Θ_{global} decreases and global peace is more likely.
- If ψ_{H_2}, ψ_{H_2-P}, ψ_{H_2-C}, and ψ_{H_2-ng} increase, then ξ_{global} increases.
- If $\phi_{pu} = \psi_{pu} - \psi_{H_2-P}$; $\phi_{cu} = \psi_{cu} - \psi_{H_2-C}$ and $\phi_{ngu} = \psi_{ngu} - \psi_{H_2-ng}$ decrease, ξ_{global} probably increases.

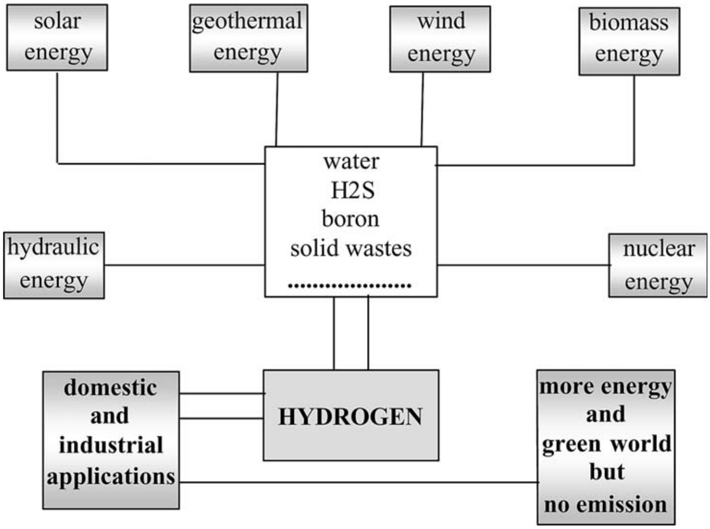


Fig. 6. Routes for hydrogen production from renewable energy sources.

4. Conclusions

This paper discusses the key role of the hydrogen economy and hydrogen energy strategies for the future in terms of global unrest and peace. Two important analytical expressions are introduced, which are dependent upon utilization ratios of hydrogen from non-fossil fuels, to describe the effect of fossil fuels on world peace and global unrest. From the main findings, including those stemming from Eqs. (13) and (19), the following conclusions are drawn:

- The approximate quantified measures developed for level of global peace ξ_{global} (ranging between 0 and 1) and level of global unrest Θ_{global} (ranging between 1 and ∞) expressions can help understand and measure levels of global unrest and global peace.
- The highest level of global peace occurs when $\xi_{\text{global}} = 1$ and correspondingly the lowest level of global unrest when $\Theta_{\text{global}} = 1$, and efforts to increase global peace and stability should cause the values of ξ_{global} and Θ_{global} to shift towards these limiting cases.
- Hydrogen from non-fossil fuels should replace oil, coal and natural gas to reduce the level of global unrest.
- When the utilization ratio of hydrogen from non-fossil fuels is lower than 100%, the level of global peace is less than 1 and one or more of the effects of global unrest are likely to be observed.

Consequently, in order to improve levels of global peace and stability, a transition to hydrogen economy should be accelerated, and the use of hydrogen energy and its systems (e.g., fuel cells) should be facilitated and implement by all possible

means. Also, in order to decrease the negative effects of using fossil energy resources, countries should increase the investments in hydrogen energy technologies employing non-fossil fuels.

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